

# A Multi-agent System for Coordinating International Shipping<sup>1</sup>

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**Abstract:** Moving commercial cargo across the US-Mexico border is currently a complex, paper-based, error-prone process that incurs expensive inspections and delays at several ports of entry in the Southwestern US. Improved information handling will dramatically reduce border dwell time, variation in delivery time, and inventories, and will give better control of the shipment process. The Border Trade Facilitation System (BTFS) is an agent-based collaborative work environment that assists geographically distributed commercial and government users with transshipment of goods across the US-Mexico border. Software agents mediate the creation, validation and secure sharing of shipment information and regulatory documentation over the Internet, using the World-Wide Web to interface with human actors. Agents are organized into Agencies. Each agency represents a commercial or government agency. Agents perform four specific functions on behalf of their user organizations: (1) agents with domain knowledge elicit commercial and regulatory information from human specialists through forms presented via web browsers; (2) agents mediate information from forms with diverse ontologies, copying invariant data from one form to another thereby eliminating the need for duplicate data entry; (3) cohorts of distributed agents coordinate the work flow among the various information providers and they monitor overall progress of the documentation and the location of the shipment to ensure that all regulatory requirements are met prior to arrival at the border; (4) agents provide status information to human actors and attempt to influence them when problems are predicted.

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<sup>1</sup> This work was performed at Sandia National Laboratories, which is supported by the U.S. Department of Energy under contract DE-AC04-94AL85000

## **I. Introduction**

A simple model of commerce divides a commercial transaction into three phases: negotiation, delivery, and settlement. This paper focuses on an agent-based electronic commerce system, the Border Trade Facilitation System (BTFS), built to expedite the regulation, control, and execution of commercial trans-border shipments during the delivery phase. The system is targeted towards the rapidly growing manufacturing industry centered around the US/Mexican border. The North American Free Trade Agreement (NAFTA) has fueled this growth to a large extent. Managing the logistics of trans-border shipments is a daunting task complicated by import/export regulations and documentation requirements promulgated by both the US and Mexico. Drug smuggling activities and drug interdiction efforts have made shipping even more difficult. The primary goal of the BTFS is to improve information handling and documentation processes for legitimate stakeholders without furthering opportunities for smuggling and other criminal activities.

The BTFS features a number of innovations, including a distributed object substrate that supports authenticated transactions among agents, a general-purpose agent development framework, agent integration with the World-Wide Web, and a collaborative agent architecture that supports open trading over the Internet. In this paper we provide only an overview of this complex information system.

## **II. Background**

Each day several thousand commercial trucks cross the US-Mexico border at six major ports of entry along the US/Mexico border. The majority carry cargo to and from the *maquilas* in Mexico. A *maquila*, or “twin plant,” typically provides inexpensive labor for the assembly of parts or subassemblies into finished goods that are then re-shipped to the US for consumption. Passage of the North American Free Trade Agreement (NAFTA) has increased maquila traffic at ports of entry along the Southwestern US border significantly since 1993. Maquila border crossings are projected to be in the thousands daily by the year 2000. Ironically, the increased border traffic has provided drug smugglers with a crowded street in which to disappear, creating a tension among US government agencies responsible for the facilitation of trade and the interdiction of drugs. The governments of the United States and Mexico currently have projects under way or planned that will expand the physical capacity of existing ports of entry. The US recently opened the a new port at Santa Teresa, New Mexico. Plans to increase the capacity for handling information necessary to document the increasing number of border crossings have not been made, largely because the majority of the information handling resides in the commercial sector.

A significant fraction of commercial trucks currently arrive at ports of entry with either incorrect or incomplete documentation. These trucks are summarily pulled over to a primary inspection area, and sometimes subsequently to a secondary inspection area, where they are often completely unloaded. Primary and secondary inspections take a minimum of 15 minutes and can last several hours or even days if problems are found. Delays typically cost both the transport provider and the manufacturer. Truck and driver costs can exceed \$100/hour. Maquilas plants are increasingly operated in just-in-time mode, so receival delays at the maquilas can result in work stoppage, idling dozens of workers and halting production lines costing thousands of dollars per minute to run. Paper documents currently carry the information needed to cross the border.

Truck drivers carry the documents and present them to inspectors at the ports of entry and exit. Many factors can cause delays at the port, including drug interdiction campaigns and fugitive alerts. Proper documentation in and of itself cannot prevent delays, but improper documentation is virtually certain to cause them.

The root causes of documentation errors are deeply buried in the complex preparations that precede a border crossing. The required regulatory documents for each leg of the trip are numerous and bilingual. Additional NAFTA requirements have complicated the documentation further while increasing the cross-border traffic, leading to the expansion of the import/export brokerage industry in both the US and Mexico. For example, a typical package prepared by a Mexican broker includes the original invoice; the Shipper's Export Declaration; a Spanish language invoice called the *factura*; an import *pedimento* (Mexican import/export declaration document); an English manifest and a Spanish *manifiesto* describing the physical nature of the shipment for the trucking firms; a packing list, describing how the shipment is actually arranged on the truck; and any of several possible Mexican regulatory compliance documents. NAFTA documents must be on file certifying the firm as a maquila, and the *pedimento* must be registered by the firm in some manner to satisfy year-end material-balancing regulations. The driver and the vehicle must be properly licensed and certified. Further complications stem from the maquilas' ability to consolidate several invoices/*facturas* under a single *pedimento*. Shipment into the US involves several additional US import documents. The documents are syntactically distinct, although there is significant semantic overlap. For example, the "total shipment value" given on many of these documents is not necessarily called the same thing between any given pair nor will the value necessarily be computed on the same basis; in particular, valuations are two different currencies.

Customshouse brokers assist manufacturers with preparing the documents for a given shipment and generally pay any duty assessed. Brokers also provide additional assurance to their clients by remaining up to date on the latest regulations regarding trade between the US and Mexico. They are essentially brokers of specialized knowledge and information, operating between government regulators and the commercial world. Brokers prepare regulatory forms from an initial manifest that may be presented by a client in a variety of forms, including "sneaker net," fax machine, Electronic Data Interchange (EDI), and most recently Internet email. Although segments of the process are computerized, transcription of information from paper to computer and back occurs often even in advanced brokerage houses. Fortunately both the US and Mexican customs services have (separate) computerized entry systems that accept document filings by modem. Nonetheless, errors occur with great regularity and brokers maintain troubleshooters on site at the ports of entry to handle such incidents.

A successful border crossing is the result of a coordinated effort on the part of the manufacturer, the consignee, and carriers and brokers on both sides of the border. For example, a nominal southbound (US to Mexico) maquila shipment involves the owner of the goods ("the firm"), the firm's US shipping facility, at least one US trucking company (perhaps owned by the firm), US customs, a US export broker (sometimes an employee of the firm), Mexican customs, a Mexican import broker (also sometimes an employee of the firm), a Mexican trucking company, and finally the maquila plant itself.

Although new port facilities are planned and expansion of old ports is has begun, traffic at the border is often backed up several miles. Often the customs district maintains several alternative ports in the same area. However, drivers cannot effectively choose an alternative port prior to enqueuing for two reasons: (1) the intended port of entry is declared on the paper document he carries and cannot be changed without resubmission to the US Customs Automated Cargo System; and (2) the driver cannot determine the traffic load (nor, therefore, estimate the delay) at the port until arrival.

Border-crossing stakeholders have noted that “the most frequent cause of legitimate freight being pulled over for inspection is improper or incomplete documentation [Godfrey 1998].” In a recent border process survey [Parker and Icerman 1996], 78% of US and Mexican firms doing business across the border cited “automated documentation” as a priority technology, the highest percentage for any technology in the survey. Stakeholders were concerned, however, that a highly-accessible electronic documentation scheme might make their proprietary information vulnerable. Commercial stakeholders were adamant that the system be decentralized; they considered a central database administered by a national government highly undesirable. The second-most frequently cited technology, “Container/conveyance tracking,” was cited by 60%. In all, technologies that the stakeholders identified as high-priority appear to address the root causes of their delays: correct, complete, and timely electronic documentation; computer-based sharing of shipment information among stakeholders; protection of proprietary information; and timely shipment status information.

Simulations of the new Santa Teresa port of entry by Science Applications International Corporation [SAIC 1997] show that computerized documentation and tracking technology would cut time spent waiting to cross the border by 33% (from 18 to 12 minutes) at 30% technology penetration and four times the current traffic, and by 52% (from 47 to 20 minutes) at 60% penetration and six times the current traffic (saturation level)<sup>2</sup>. These reduced waiting times would be enjoyed by all vehicles, not just those with advanced technology. If a dedicated lane for advanced technology vehicles is added in the latter case, those vehicles would enjoy a reduction in waiting time of 75%.

In 1997 the Advanced Information Systems Laboratory (AISL) at Sandia National Laboratories completed a prototype of the Border Trade Facilitation System (BTFS), a collaborative information processing environment that operates on the Internet and World-Wide Web. The BTFS comprises multiple autonomous software agents that assist human actors in conducting international shipping transactions by creating, documenting, monitoring, and coordinating shipment transactions in information space. The BTFS attacks the border-crossing problem in the three problem areas with the highest potential for improving the border-crossing process: (1) manual entry of redundant information throughout the process by different organizations; (2) incomplete regulatory documents; and (3) lack of timely status information regarding the location of the vehicle and the progress of the documentation. We discuss the conceptual design and implementation of the BTFS in the remainder of this paper.

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<sup>2</sup> “Current traffic” refers to 1995-96 levels; traffic grew 80% during the 1996-97 year and is thus already at twice the “current traffic” level.

### III. System Concept

The essential concept of the BTFS is that the physical trans-border shipment of goods and the required accompanying certification are entirely represented as a set of events in information space, the state of which both controls and certifies events in physical space. The BTFS information system contains a real-time transaction-centric model of the physical border-crossing process. This leads to a two-component system: (1) a physical sensor system that reports state of health and location data via satellite [Schoeneman and Fox 1996]; and (2) a secure electronic commerce system that interfaces with the humans responsible for documenting commercial and regulatory information. We will focus on the secure electronic commerce system for the remainder of this paper.

Coordination of the shipping process to improve the timeliness and correctness of the information requires a collaborative information processing network that spans government and commercial entities, involves both the US and Mexico, and passes Spanish and English-language documents. Security to protect proprietary information is of paramount importance to commercial entities. Security is also critical to government agencies; an insecure system on the open Internet could be used to spoof regulatory agencies at the border and thereby lend support to criminal activities such as drug smuggling.

The ultimate objective of the system is to ensure that the US and Mexican Customs databases contain validated documents when the truck arrives at the border. The truck cargo must have a unique ID code that identifies it with its counterpart (representation) in information space. An enforcement officer must use this code to reference the documents and make an inspection decision. The flow of data through the system is transaction-centric; each new shipment instance is a new transaction. A transaction is initiated by the ultimate customer—the manufacturer—either on the shipper side or the consignee side. A transaction may be open for long periods; many days in some cases.

To achieve the level of integration and information quality envisioned by the border stakeholder community, the BTFS is based on multi-agent concepts and technology. Software agents elicit specialized information from human informants, monitor overall progress of the documentation task, monitor the location of the shipment via tracking sensors, coordinate the work flow, and attempt to influence human actors when problems are predicted or detected. Agent functions are realized by goal-directed agents specializing in various tasks in the import/export domain.

The BTFS design is based on three general concepts: (1) creation of a distributed object programming environment with an underlying secure network infrastructure; (2) a distributed object representation of a shipping transaction; and (3) insertion of knowledgeable software agents at critical points in the information flow. Since the stakeholders in the border shipping domain are geographically distributed independent organizations, the Internet provides a ready-made communications infrastructure to integrate their operations. Using the open Internet as the communications infrastructure accommodates any commercial organization with access. Security is provided by public-key encryption and authentication techniques. Our initial approach suggested that the Internet, with its high ramification and ubiquity, would be well suited for the BTFS if security issues were addressed. Assuming this can be accomplished, the Internet goes well beyond merely satisfying BTFS requirements; with the BTFS in place,

one could conduct international commerce from any site with an Internet connection and a web browser. The Web, nearly as far-flung as the Internet itself, also suggested HTML as the *lingua franca* of the BTFS, thus obviating the user interface dilemma and neatly solving the client end of the system. In the BTFS, a highly specialized agent converts HTML from the client into the central ontology and back.

Overlying the secure Internet is a distributed object programming system that provides a seamless design methodology for networked object environments [Spires 1997]. The distributed object system is essential to networking agents in a collaborative environment. Distributed object technology also supports a shared fragmented workpiece object. The information needed to effect a single shipment is captured in a complex distributed information structure with compositional semantics called the Maquila Enterprise Transaction (MET). The components of a given MET are distributed among the agencies involved in a particular shipment. The MET is shared via proxy; when a given agent needs information in the MET, it is handed the proxy to the MET. Since the MET is distributed, no one agent or agency has access to all components. Access is permitted based on task requirements and controlled by electronic signature. BTFS agents interact with the border-crossing process by collecting and organizing information and posting it in the MET. Control of the distributed computation is decentralized and opportunistic. Each agent computes new information components based on its internal knowledge base and the state of the MET. Changes in the components trigger computations in a manner reminiscent of blackboard systems [Englemore and Morgan 1987].

Agents improve the border crossing process in the following manner:

- Document quality is improved by elicitation agents. Elicitation agents interface with human informants and specialists to elicit highly structured forms-based data, ensuring that proper documents are entered into the system. Elicitation agents have significant knowledge about the domain and the forms, and they are able to present partially-instantiated documents through use of a case-based reasoning mechanism. Elicitation includes mediation of information from other documents to remove the opportunity for redundant data entry. Invariant data from previously completed documents, having been validated by other elicitation agents and not the responsibility of the current human informant, is translated into the target document's ontology and copied into a non-editable field of the target document.
- Timeliness of documentation and integration of shipment information is improved by an agent collective comprising agents from different organizations that monitor status and coordinate work flow. The collective correlates the physical state of the shipment with its information state to maintain registration and reference, mediates the agency's work on the transaction, updates the transaction, notifies collaborators of updates, and enforces selective data sharing. Monitoring is accomplished by each agent independently and focuses on the interests of its parent organization. Agents respond to requests for status information by users.
- An open decentralized trading regime is ensured by negotiation agents.



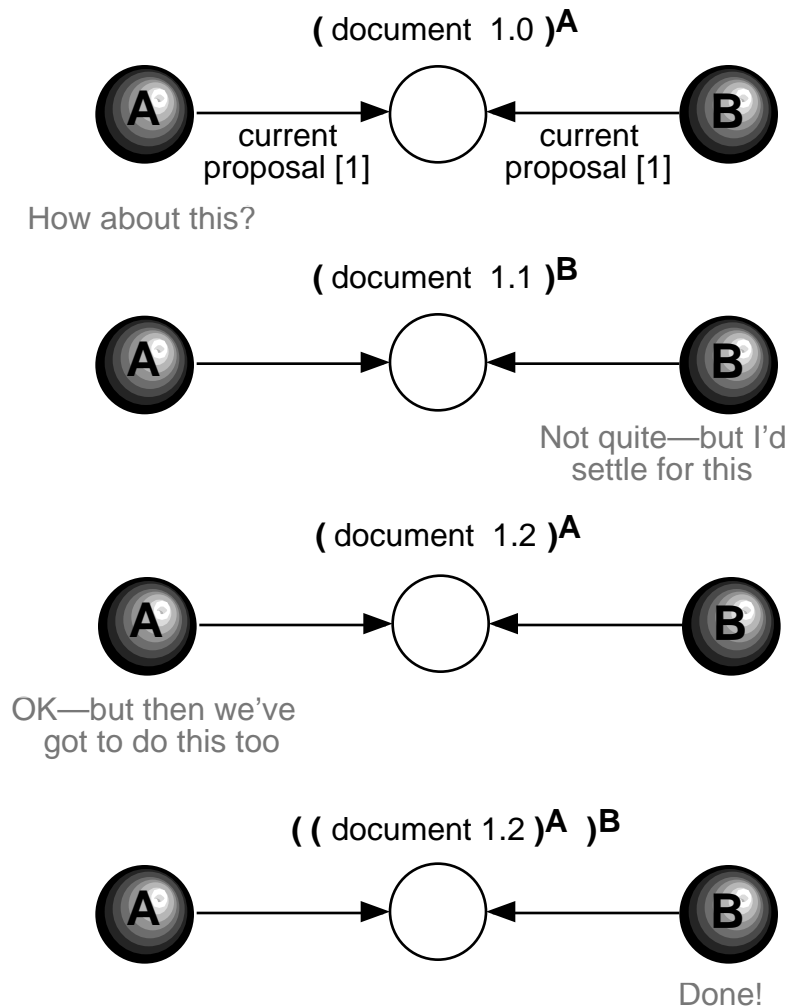
Negotiation and delegation behaviors provide coordination of the workflow and timely completion of all documents. Agents coordinate their activities through direct communications and explicit cooperative control [Lesser 1991]. Customer agents negotiate task specifications with supplier agents. When a contract is negotiated and the supplier agent commits to perform the services, the customer agent delegates the task to the supplier. Throughout the negotiations, each proposed new version of the task is signed by the proposing agent with a cryptographic digital signature (Figure 2). Agent “A” signs with the signature denoted “A;” agent “B” signs with signature “B.” The final contract is signed by both agents. The basis of coordinated negotiation and delegation is very similar to a joint intentions protocol [Levesque et al. 1990; Cohen and Levesque 1991]. We have added public-key digital signatures to all negotiated forms and tasks for accountability and non-repudiability. This is an essential feature for commercial trading applications. Delegation is shown schematically in Figure 3. A goal or task is passed from a “boss agent,” who retains responsibility for the goal, to a “worker agent,” who must commit to achieve the goal or report defaulting. If the delegate defaults, the delegator is responsible for finding another qualified delegate.

#### **IV. Implementation of Agents**

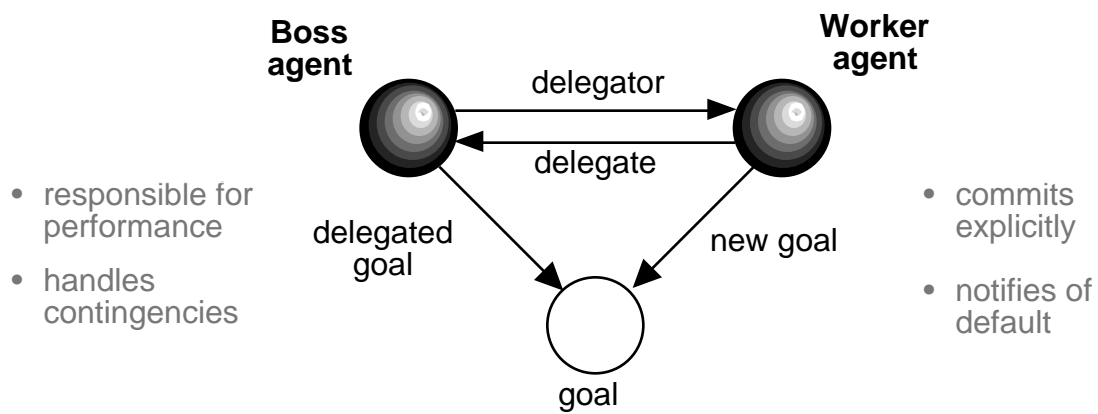
Agent populations are organized into *agencies*, collectives of agents of various competencies, that have ongoing high-level goals stated in business terms. In particular, the BTFS is a distributed set of agencies specialized on the commercial functions of the various stakeholders in the border-crossing process.

The agents that populate the BTFS are realized as instances of specialized agent classes whose behavioral envelope is defined by the Standard Agent Framework [Goldsmith 1997]. The Standard Agent Framework is an object-oriented framework that enables the exploratory development of multiagent systems that interact with human users. The Standard Agent Framework provides a means for constructing and customizing multiagent systems by specialization of base classes (architecture-driven) and by composition (data-driven).

The framework comprises two associated abstract classes: *agent* and *agency*. An *agency* identifies an independent locus of processes, activities, and knowledge typically associated with an company, organization, department, site, household, machine, or some other natural partitioning of the application domain. The underlying assumption is that the application is naturally modeled as a group of interacting agencies. The agency provides a containing context for a collection of agents. The activities of the agency are conducted by its constituent agents. Agents inhabit an agency for the express purpose of providing *services*, including interagency communications, that maintain the functioning of the agency and lead to satisfaction of the ultimate objectives of the agency. An agent performs domain-specific tasks on behalf of human actors and other agents.



**Figure 2. Negotiation between two agents**



**Figure 3. Delegation**

Actual agent systems are implemented by the specialization and instantiation of four concrete classes: (1) Standard Agency; (2) Standard Agent; (3) Human Actor; and (4) Resources. The class Standard Agency is an elaboration of the agency concept that includes human activities within the agency and devices for data-oriented activities such as storage and communications. An instance of Standard Agency is a persistent, identity-bearing composite object that contains collections of the component classes Standard Agent, Human Actor, and Resources.

The class Standard Agent implements instances of agents that have specific attributes: autonomy, social ability, reflexivity, and pro-activeness [Wooldridge and Jennings 1995]. The primary Standard Agent protocols are an interface mechanism that enables interaction with other agents and human actors, a reflexive action mechanism for rapidly responding to event objects in the agent's environment, and a generic inference mechanism for achieving explicit goals. The interaction and inference protocols can be specialized with methods that implement other agent architectures and mechanisms. Agents are self-contained threads of execution that execute both periodically and through immediate scheduling.

Human Actors are people that inhabit the agency through an interface device and interact with agents to accomplish tasks. Human actor objects are temporary objects that contain an interface address, an interface object that captures the display, data entry and control functions currently available to the person, and a persistent person object that holds personal data, passwords, email address, and an account object that provides access to past and current workspaces. A workspace object contains objects created and stored by the person during work sessions.

Agents and human actors have access to *resources* such as databases, fax machines, telephones, email handlers, and other useful services. Resource objects provide concurrency control and access protocols for agency resources. Subclasses of the resource class implement objects representing data bases, fax machines, printers, email ports, EDI ports and other commonplace legacy devices in the agency environment.

The Standard Agent Framework supports distributed agent systems. Agency objects may be distributed in a network environment to create a collaborative enterprise structure of interconnected agencies. The fundamental activity conducted among distributed agencies is the trading of domain objects through proxy agents that represent one agency within the agent collection of another agency. These proxy objects delegate all messages (except for a local request for identifying information about the represented agency) to the appropriate domain or task agent residing in the agency. Public proxies are registered in an agency network phonebook with a well-known address. To find other agencies, an agent issues one or more queries to the phonebook and is returned the proxy objects matching the query. The agent proxies interned within an agency form a persistent network of agencies. Such networks are called *durable proxy networks*.

An *electronic commerce agency* (ECA) is a specialized subclass of an agency that implements architectural features specific to electronic commerce applications. An ECA has the additional attributes of *transactions* and *organizations*. The transactions attribute holds a collection of open and closed transaction objects. The organizations attribute

holds a collection of public proxy objects pointing to agencies that represent trading partners.

The BTFS agent society comprises several federated ECAs analogous to the interested business entities. Each ECA is populated by a heterogeneous collective of speciated agents, each of which is able to perform a fragment of the information tasks needed to effect trans-border shipment. Their exact duties are based on the idiosyncratic business rules of the actual businesses involved, so an operational ECA must be tailored and situated for each business. Constructing the ECA and the agents that make it up consists in specializing agents from a set of standard agent classes constructed for commerce. ECA classes are also pre-defined for the various required roles: originator, receiver, transport provider, and import/export broker.

In addition to domain and task specialists, several varieties of housekeeping agents perform maintenance tasks for the ECA. Security agents control access by human actors to each agency within the parent organization. A human actor logged into the ECA “inhabits” the agency for the duration of the work session. An agent handles all interactions with the human actor. Task agents initiate requirements to obtain information based on activated goals, monitor the appropriate information sites to see whether the goals have been achieved, and take corrective or contingency measures when failures occur. Dispatch agents allocate new transactions to the appropriate agents. Supervisory agents allocate work to task agents, deal with rejected goals, collate agency-level data, and respond to outside requests for task status information. Various agents incorporate reporting facilities for human actors, including government customs on both sides of the border.

## **V. Conclusions**

The BTFS prototype demonstrates a multi-agent approach to coordinating a complex, knowledge-intensive shipping process. We have demonstrated the following agent behaviors: elicitation, mediation between ontologies, negotiation, delegation, monitoring, and goal satisfaction. We have demonstrated an authenticated negotiation protocol for commercial contracts.

The most challenging aspects of integrating a diverse enterprise such as border trade are: (1) knowledge-intensive elicitation of form information; (2) mediation and ontological leveling of information across multiple organizations; (3) knowledge engineering in general; and (4) secure distributed object computing.

The BTFS system is currently being evaluated for commercialization.

## **VII. Acknowledgements**

The authors express their gratitude to John Wagner of the New Mexico Alliance for Transportation Research for his support of this project.

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